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## Abstract

## Full Text

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## PHYSICS

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# GENERATION OF COHERENT RADIATION IN GALLIUM ARSENIDE SAMPLES UNDER ELECTRON EXCITATION

*(Presented by Academician A. A. Lebedev, March 15, 1965)*

In paper ([1]) the generation of stimulated radiation upon excitation by an electron beam of cadmium sulfide samples was reported for the first time. Subsequently this excitation method was used in work ([2]) and gave positive results on InSb and InAs samples at low temperatures. Generation in *p*-type GaAs samples under electron excitation at a temperature of 4.2° K was also reported ([3]).

In our work it is shown that the generation of coherent radiation under electron bombardment of GaAs is possible not only at helium temperatures, but even at nitrogen and room temperatures.

In InSb and InAs it is easier, for a number of reasons, to obtain coherent radiation. Using known calculation methods ([4]), it is easy to show that the conditions for inverse population of the bottom of the conduction band relative to the ceiling of the valence band in these materials are substantially less stringent than in GaAs, because of the very small effective masses of electrons in the conduction band and the narrower forbidden bands. In addition, the lifetime in GaAs is very short ([5]). Therefore the inversion conditions correspond to an electron-gas temperature equal not to the lattice temperature ([6]), but to the Debye temperature ($Q_l = 410$°K) ([7]). Under these conditions one may expect that, in the lattice-temperature interval 77—300° K, the magnitude of the threshold current will depend only weakly on temperature, since the electron-gas temperature is equal to the Debye temperature.*

As calculation shows, in GaAs, already at $n \simeq 2 \cdot 10^{18}$ cm$^{-3}$ and 410° K, inverse population of the bottom of the conduction band relative to the ceiling of the valence band takes place, since the effective mass of electrons in the conduction band is small, although it is larger than in InSb and InAs.

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We observed generation of coherent radiation from homogeneous *n*- and *p*-type GaAs samples at nitrogen and room temperatures, having Fabry—Perot resonators. In the experiment an electron-beam apparatus was used that made it possible to obtain electrons with energies up to 60 keV. The electrical circuit of the electron source made it possible to regulate the accelerating voltage, the beam current, and the diameter of its cross section. The experiment was carried out in a pulsed mode with exciting-pulse duration $9 \cdot 10^{-8}$ sec and repetition frequency 50—200 Hz. The maximum beam current was 17 mA with electron-beam diameters 60—70 $\mu$. The resulting concentrations of nonequilibrium carriers exceeded the theoretic—

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* If it is assumed that in InSb the electron gas is likewise at the Debye temperature, the inversion conditions will be less stringent than in GaAs, owing to the fact that the Debye temperature is lower than the corresponding value for GaAs. In the case when InSb is sufficiently pure and the lifetime, determined in this case by radiative recombination, is sufficiently large ([7]), one may expect that the electron-gas temperature is equal to the lattice temperature. If the latter is below $Q_l = 290^\circ$ K ([6]), then the inversion conditions will be still less stringent, and the value of the threshold current will depend on temperature. Apparently, analogous arguments are applicable to InAs.

calculated values necessary for obtaining an inverted distribution.

The samples studied were soldered to a copper substrate, cooled to 77°K, which was placed in a vacuum chamber. The electron beam was incident normally on the polished surface of the samples, and the radiation was observed from faces perpendicular to the plane of incidence. An electro-optical converter was used as the radiation receiver.

Fig. 1
**Fig. 1**

Fig. 2
**Fig. 2**

Samples of *n*- and *p*-type GaAs with Fabry—Perot resonators were subjected to irradiation by an electron beam. The resonators were obtained by cleaving along the (110) plane and had a length of 50–60 $\mu$.

Figure 1 shows the radiation pattern of an *n*-type sample at 77°K in the generation regime, when a Fabry—Perot etalon was placed in front of the converter photocathode. Figure 2 illustrates the radiation pattern of a *p*-type sample at 300°K. In addition, in experiments in which the electro-optical converter was placed directly in front of the sample, vertical bands were observed, fitting completely on the converter screen. This confirms the directionality of the radiation.

The experimentally observed values of the threshold-current density for different samples lie in the range 70–150 A/cm$^2$. According to preliminary measurements,

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the magnitude of the threshold current is practically independent of temperature. This indicates that radiative recombination occurs under conditions in which the temperature of the electron gas is equal to the Debye temperature. More detailed measurements of the radiation characteristics of the samples are currently being carried out.

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*Note: Figure translations are in progress. See original paper for figures.*

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